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Improvements to speech quality from a diving helmet

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Summary

The normal quality of speech received from a microphone in a diving helmet is far from acceptable for broadcasting. It is both severely distorted in terms of spectral content and, where air is supplied to the diver via a 'demand valve', the noise level from the demand valve is extremely high. This Report examines these problems and suggests ways in which they can be overcome, without losing the verisimilitude of the event.

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1. Introduction

In recent years a number of occasions have arisen where BBC producers have wanted to include speech from a diving helmet in their programmes. Although on the different occasions the problems the producers were experiencing were different in detail, they fell clearly into two categories. These were first the spectral distortion of the sound which gave rise to poor intelligibility and, secondly, the problem of noise from the diver's air supply, which on occasions was positively distracting.

This Report looks at the difficulties of obtaining useable speech quality from a diving helmet and suggests ways in which the quality can be significantly improved.

2. Typical diving situations

One programme in which these problems were encountered and where assistance was requested from Research Department was an occasion where a producer and a specialist in marine biology were proposing a series of seabed walks with discussions on the visible marine life. On this occasion the events were to take place close to the shore or to a support vessel and so they were proposing to use a 'free-flow' air supply†. Thus there would be a continuous, but acceptable, background hiss from the air supply. However, the helmet shown in Fig. 1 produced gross colorations of the sound which needed attention before the recordings could be broadcast.

On a subsequent occasion, assistance was needed in connection with a programme in the 'Origins' series, on the underwater surveying and possible recovery of the 'Mary Rose', the flagship of Henry VIII, which capsized in 10 fathoms of water off the Southsea Castle in 1545, see Fig. 2. On this occasion, there were no facilities on the support vessel, the 'Sleipner', for free-flow air supplies and it was thus necessary for the divers to use on-demand air supplies. In the event, a very similar design of helmet was adopted to that used in the previous case, see Fig. 2b, but on this occasion the diver wore air cylinders and a demand valve was fitted into the front of the helmet, close to the built-in microphone. Thus, each time the diver inhaled, the demand valve opened causing a rush of air past the microphone. This generated a blast of noise on the recording, significantly above speech levels, and as the diver tended to inhale once every four to six seconds, the blasts of noise were extremely distracting to anyone listening to the untreated recording. In this case, it was obviously necessary to treat both the colorations caused by the helmet, constituting an enclosed cavity around the microphone and the demand valve noise.

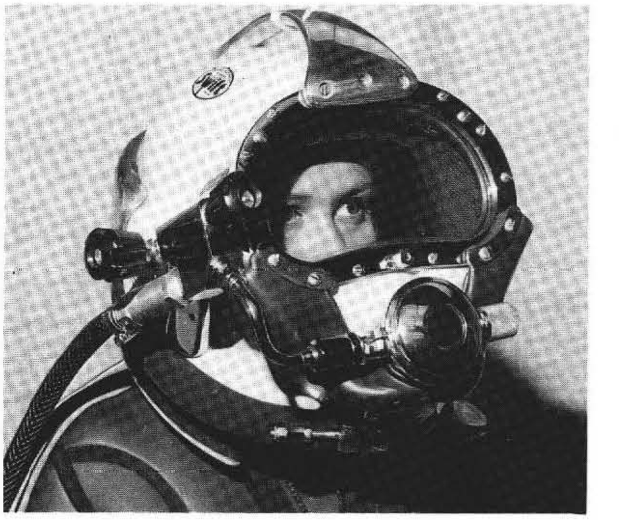

Fig. 1 — Diving helmet using free-flow air supply

3. Signal equalisation

The ideal solution to the colorations generated by the helmets would have been to insert acoustically absorbent material in them in much the same way as sound absorbing material is installed in studios. However, not only would this have been impractical in such a confined space, but there were obvious safety aspects to consider. An alternative was to try to compensate for the colorations by means of equalisation, i.e. spectral shaping of the speech signals. This can only ever be a palliative, as the colorations introduce both spectral and temporal changes to the original sound, whilst equalisation merely offers spectral compensation. However, it is often surprising how much can be

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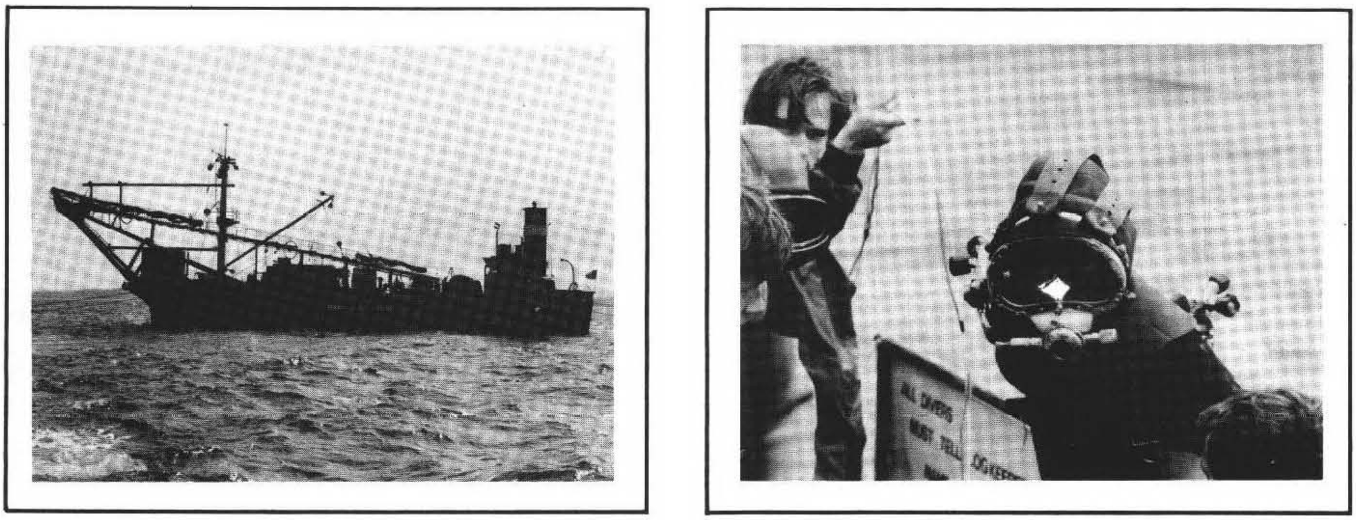
† Two forms of air supply are used in diving. Free-flow supply where air is pumped continuously via an umbilical cord from the shore or a ship to the diver, and on-demand supply, where the diver carries compressed-air cylinders and air is supplied via a demand valve as the diver inhales.



(a) The support vessel, the 'Sleipner'

(b) Diver wearing helmet with on-demand air valve, built-in microphone and communications cable.

Fig. 2 — Collection of material for the 'Origins' programme on the 'Mary Rose'

achieved by equalisation, particularly in cases such as this where studio quality is not only unattainable but, for artistic reasons, undesirable.

In advance of programme recordings, several tests were carried out in the laboratory in order to derive the necessary equalisation characteristic. Speech tests were made with one female and two male voices from a helmet and the equalisation shown in Fig. 3 was quickly derived subjectively. As expected, the original sound was extremely bass heavy due to the enclosed volume of the helmet. It also exhibited severe mid-frequency resonances due to eigentone modes within the helmet. When the illustrated equalisation with its notch at around 1kHz was applied to the microphone signal there was a marked improvement in the intelligibility of all three voices and the sound was judged to be of broadcastable quality. Inevitably, small individual differences were felt to be artistically beneficial, between one voice and another, but it was felt that these could be applied during the editing part of the programme production, using conventional mixing desk facilities.

In the case of the dive on the wreck of the 'Mary Rose' however, somewhat different equalisation was found to be necessary. The bass and top cuts remained substantially as shown in Fig. 3 but the optimum frequency for the notch was found to be closer to 2kHz than 1kHz. It appeared, therefore, that the precise way in which the helmet is worn, particularly regarding the force with which the webbing holds the mask against the diver's face,

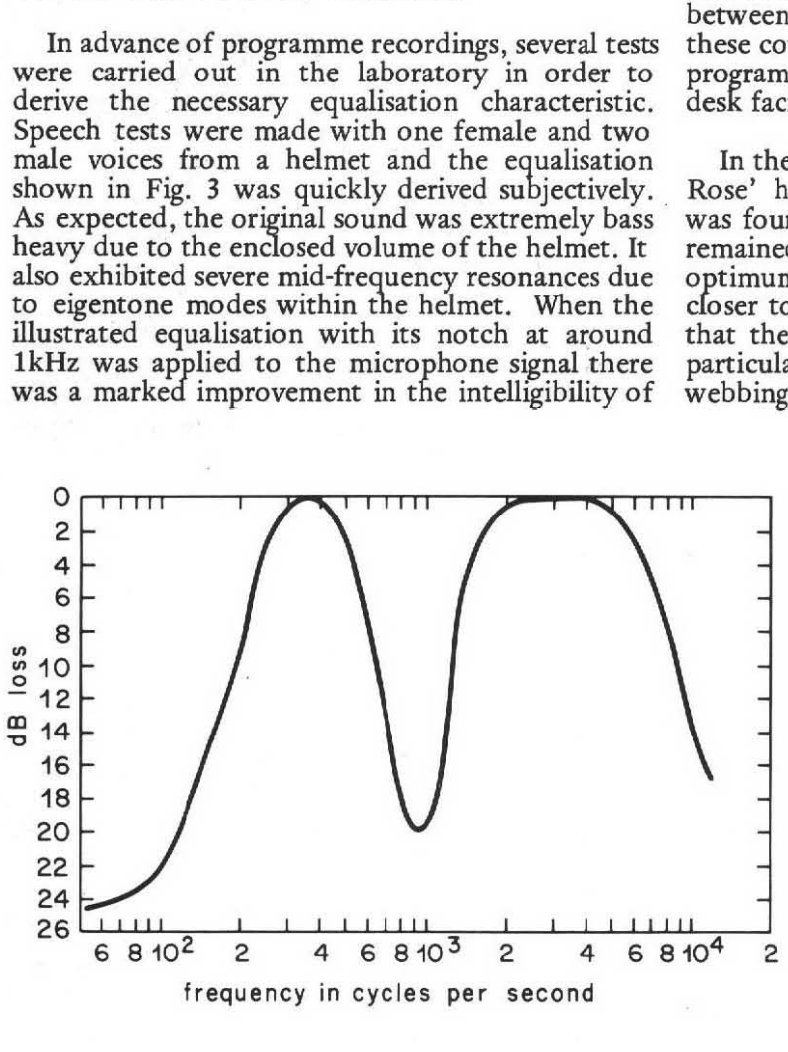


Fig. 3 — Subjectively derived equalisation for the microphone output

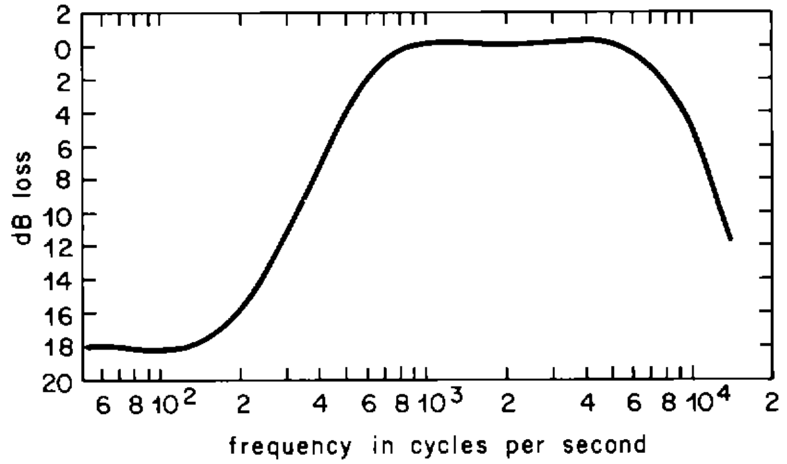


Fig. 4 – Subjectively derived equalisation for the headphone feed

affected the resonant frequency of the helmet cavity. Therefore, it is recommended that the notch part of the equalisation should be adjusted as part of a post-recording dubbing/mixing operation. On the other hand the low frequency (and possibly the high frequency) equalisation could usefully be done at the recording site. Not only would this improve local monitoring intelligibility, but by attenuating the very marked bass rise, the equalisation would improve the signal-to-noise ratio on replay of the on-site tape recording.

As well as the microphone, the helmets were equipped with a pair of headphones for surface-to-diver, or diver-to-diver communication. Although these were of acceptable quality, it was again found in the laboratory that a bass cut in the headphone feed improved intelligibility to the diver. There also seemed little point maintaining sensitivity above 5 kHz as this only increased the noise bandwidth and thus a headphone equalisation as shown in Fig. 4 was derived.

In view of the close proximity of the headphones to the microphone in so confined a space, it was felt advisable to determined the level at which acoustic feed-back might occur. However, even at headphone sound levels of 100dBA there was no evidence of howl-round. On the other hand, high levels in the headphones could cause problems for the diver himself and so the potential power output of the headphones was measured. For an input power of 30mW, a sound level of 100-110dBA was measured at the diver's ears using male speech as a programme source. Reference 1 discusses the risk of hearing damage from high intensity sounds generated by headphones. In the course of that investigation it was found that even inexpensive, commonly-available, low-impedance headphones could generate sound levels of 160dBA. This is certainly sufficient to cause instantaneous, irreparable hearing damage and much lower levels will cause disorientation and confusion. A diver is clearly in a most vulnerable position since he cannot control the sound level, nor can he remove the headphones.

It is, therefore, strongly recommended that the power capability of the amplifier feeding such headphones should be limited to 30mW so that even in the event of fault conditions, such as howl-round or circuit discontinuity, power levels in excess of that figure cannot be generated.

4. Active noise suppression

The other main problem was that of noise due to the operation of the air-supply demand valve. It was found that the noise level from the microphone during inhalation was up to 20dB higher than the signal level during speech, as shown in Fig. 5. Although the two obviously did not occur together, the diver was breathing on average once every five seconds and thus the on-site recording contained very frequent, extremely high level bursts of noise. One solution would have been to edit the tape, but it seemed likely that an electronic circuit could be devised to process the recordings automatically. An initial solution was sought using a COPAS-1 digital audio processor[2] which was programmed† to detect the high frequency demand valve noise and attenuate the output during this period by a preset amount. This technique was used successfully to process the 1980 season of recordings from the 'Mary Rose' but, for several reasons, it was felt that the availability of a self-contained portable processor would be beneficial. For instance, on-site processing could

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† This work was carried out by P.S. Gaskell

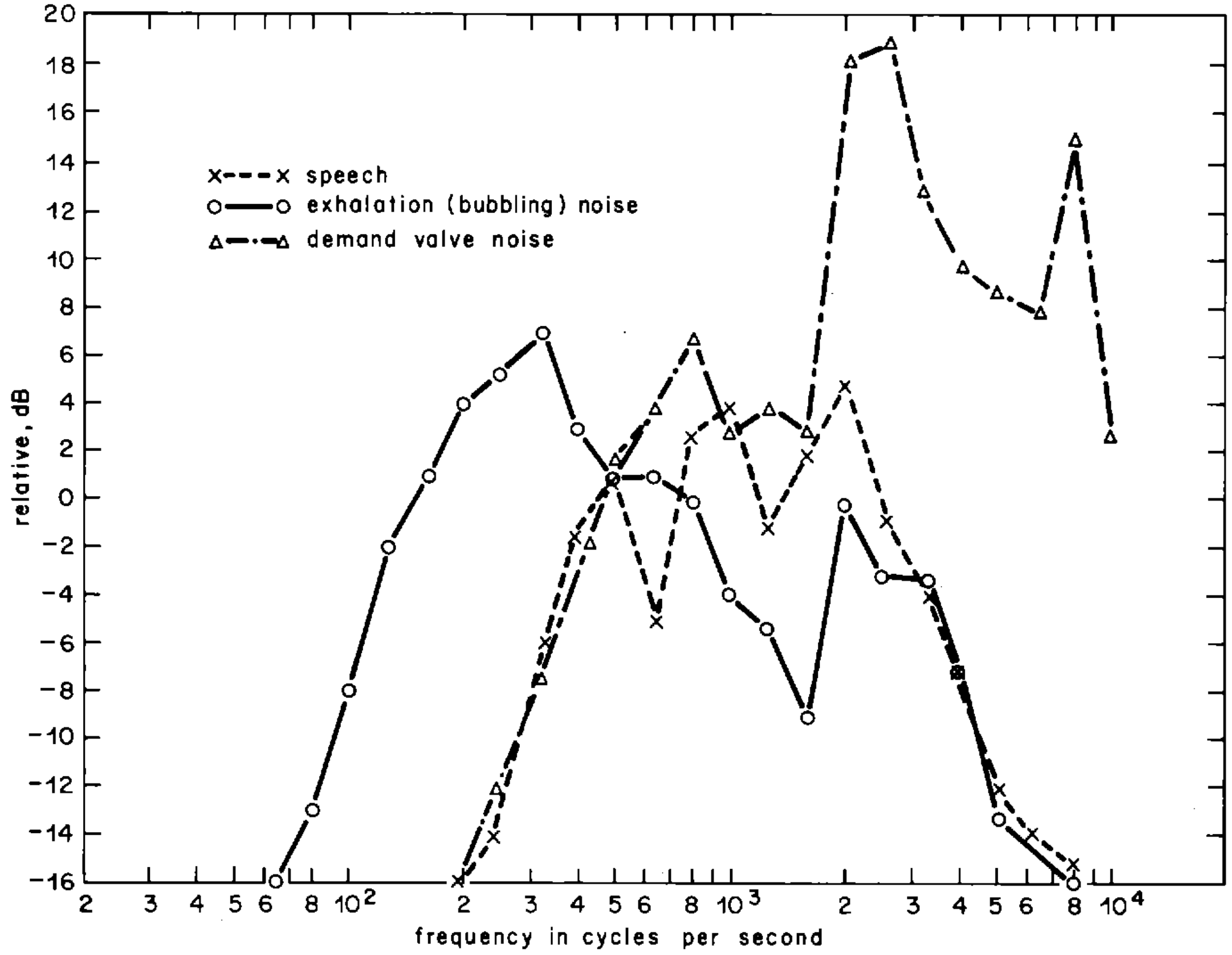

Fig. 5 — Relative spectra of speech and noises

again enable a better overall signal-to-noise ratio to be obtained on the initial tape recording. Also the same system could be used for on-site monitoring of the diver's messages which, because of the very high-level high-frequency noise blasts from a loudspeaker in a non-acoustically treated steel cabin had proved to be extremely fatiguing to the listening support crew. A simple analogue processor[3] was therefore built; see Fig. 6.

The principle of operation of the active noise suppressor is shown in Fig. 7. The input audio signal is passed through a bandpass filter, tuned to the central frequency of the demand valve noise, and thence to a rectifier/integrator. The output of this is then compared to a preset threshold. When the demand valve noise exceeds the threshold a variable attenuator is triggered to attenuate the audio signal, thus completing the operation.

This mode of operation obviously depends on the demand valve noise being louder than any speech signal in a certain frequency band, see Fig. 5. Thus, the threshold level is set to be above the normal speech levels in that band, but below the demand valve noise levels.

However, two things complicate this otherwise simple device. First, the frequency content and level of the demand valve noise vary during a dive according to the pressure difference across the demand valve and, hence, the pressure in the diver's air cylinders. This dictates that both the frequency of the bandpass filter and the threshold level must be variable. Because of this variability and the possible need to use the processor 'live', a second complication was felt necessary, namely to duplicate the bandpass filter. This would enable one circuit to be used on-line, on a previous setting to process the audio, whilst the operator adjusts the other circuit off-line to search for a better setting as the demand valve noise slowly changes.

A detailed block diagram is shown in Fig. 8. The audio signal is fed first to an attenuator which is used to set the level through the detectors and thus

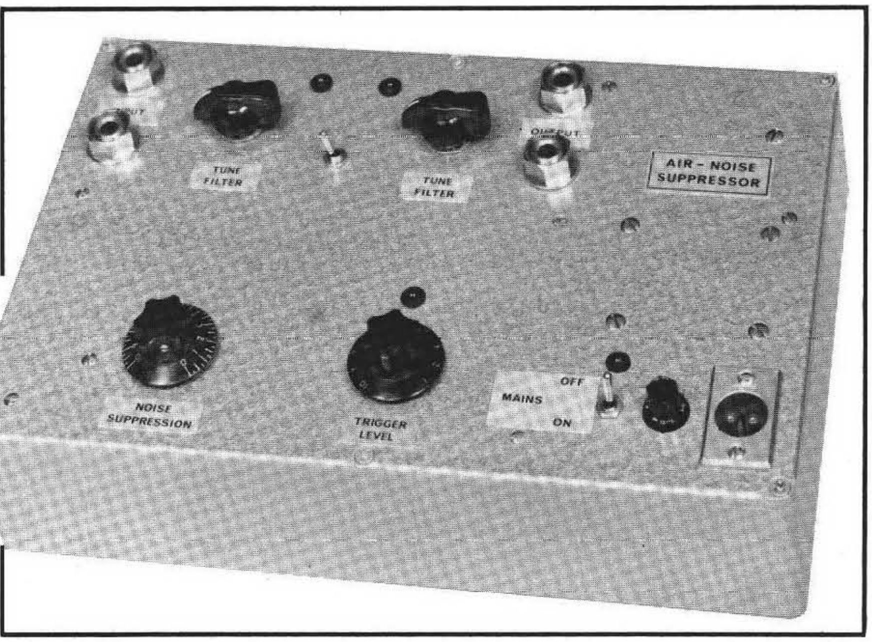

Fig. 6 — The active noise suppressor

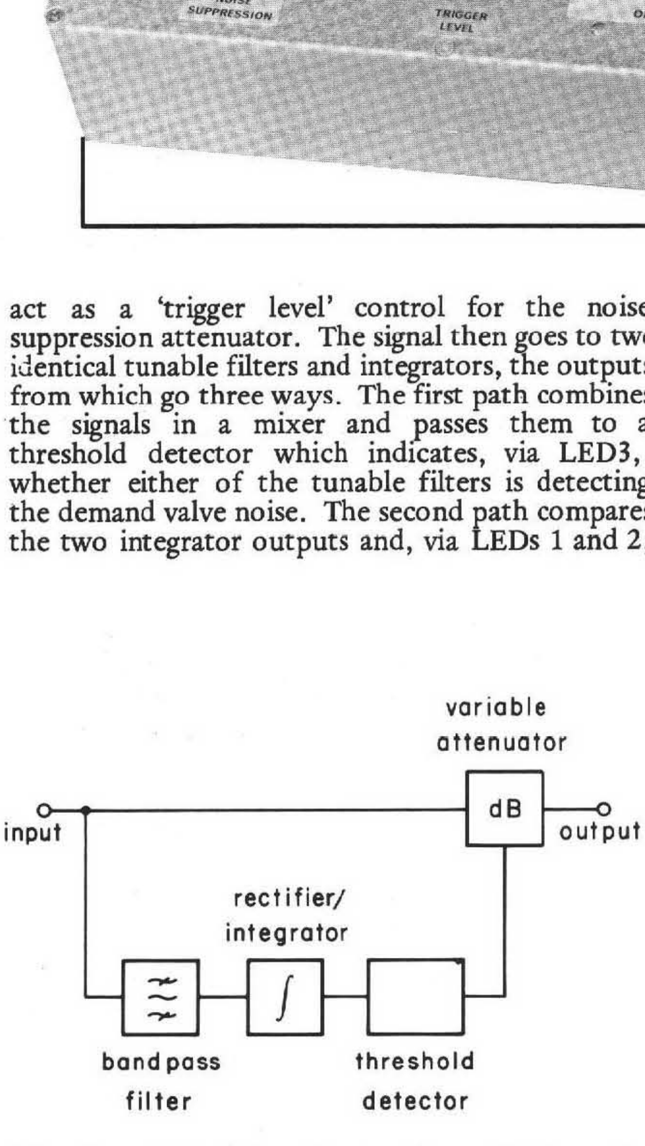

Fig. 7 — Principle of operation of the noise suppressor

act as a 'trigger level' control for the noise suppression attenuator. The signal then goes to two identical tunable filters and integrators, the outputs from which go three ways. The first path combines the signals in a mixer and passes them to a threshold detector which indicates, via LED3, whether either of the tunable filters is detecting the demand valve noise. The second path compares the two integrator outputs and, via LEDs 1 and 2, indicates which of the two circuits is detecting the demand valve noise more consistently. Finally, on the third path because of the nature of the integrator output signals and the design of the variable attenuator, the integrator outputs are used to drive the variable attenuator directly. One or other of the integrator outputs is selected manually, via switch SW3, and is fed to the FET gate in the variable attenuator. Also fed to the variable attenuator is a buffered feed of the input audio signal. This passes via VR1 and the FET source to the output buffer amplifier. The degree of noise suppression during the detected period of demand valve noise is set by the ratio of VR1 and and the FET 'on' impedance.

The noise suppressor has been found to be very simple to adjust and has been used successfully in many post-recording dubbing sessions.

5. Conclusions

It has been found possible to process speech from diving helmets to a quality suitable for broadcasting. The techniques adopted are spectral shaping (equalisation) and a particular form of active noise suppression. With the aid of these two techniques, speech signals from divers have been processed successfully and broadcast.

Although the active noise suppressor was developed specifically with normal air breathing in mind, other areas of application are envisaged. A helium-air mixture causes a pitch change to speech sounds, but it is expected that a change in the frequency of the detector's tuned filters will enable the technique to be applied under these conditions. Outside the realm of diving, similar noise-suppression techniques could be applied anywhere where air is supplied through a demand valve, for example, to breathing apparatus for fire fighters equipped with radio

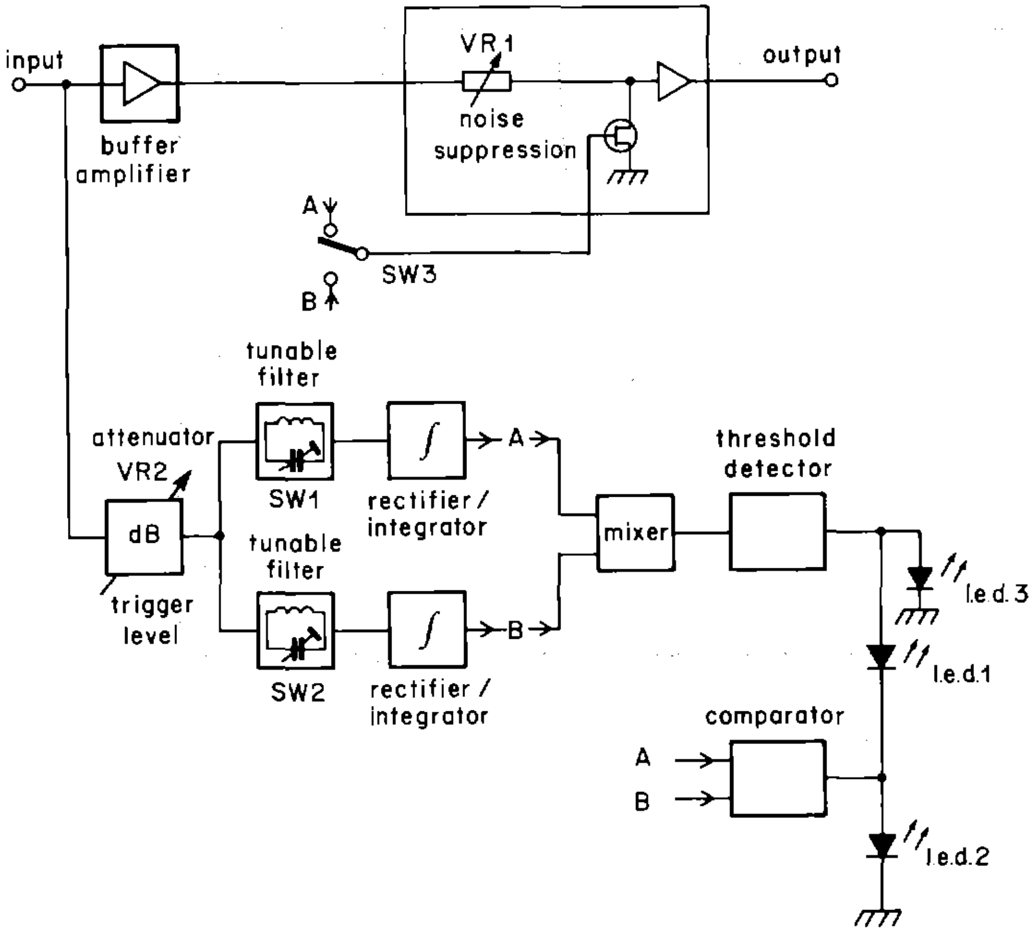

Fig. 8 – Detailed block diagram of the noise suppressor

links to a control point.

Finally, it was found that the low impedance headphones built into the diving helmets were capable of producing very high sound levels at the diver's ears. It is, therefore recommended that the ouput from the amplifier feeding the headphones should be limited to 30mW. This will limit the sound level to 110dBA even under fault conditions.

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